Associate Sneutrino-Neutralino/Chargino Production at LEP⊗LHC

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Abstract: We examine for representative gaugino-higgsino mixing scenarios sneutrino-neutralino and sneutrino-chargino production in deep inelastic ep-scattering at $\sqrt{s} = 1.8$ TeV. The cross sections for sneutrino-chargino production are more than one order of magnitude bigger than those for sneutrino-squark production. Also for zino-like neutralinos we find cross sections at least comparable to those for $\tilde{\nu}\tilde{q}$-production.

1 Introduction

Associate production of sleptons and squarks ($ep \rightarrow \tilde{l}\tilde{q}X$) at HERA and LEP⊗LHC has been extensively discussed by numerous autors, see e.g. [1,2]. If, however, squarks are heavy but sleptons are relatively light then these processes are suppressed or even unaccessible and the associate production of a slepton and a neutralino $\tilde{\chi}_i^0$ or a chargino $\tilde{\chi}_i^\pm$ become the most important SUSY processes at ep-colliders

From the five possible processes which on the parton level are (i) $eq \rightarrow \tilde{e}\tilde{\chi}_i^0 q$, (ii) $eq \rightarrow \tilde{e}\tilde{\chi}_i^+ q$, (iii) $eq \rightarrow \tilde{e}\tilde{\chi}_i^- q$, (iv) $eq \rightarrow \tilde{\nu}\tilde{\chi}_i^0 q$, (v) $eq \rightarrow \tilde{\nu}\tilde{\chi}_i^- q$, only the associate production of the lightest neutralino $\tilde{\chi}_1^0$ has been investigated in the deep inelastic region [3], assuming however, that it is a pure photino. We have examined for LEP⊗LHC and some representative SUSY-scenarios the five channels (i) to (v) and give in this paper some numerical results for associate sneutrino-neutralino/chargino production.

Distinguished by remarkably large total cross sections and interesting signatures, which will be – as well as the standard model background – briefly discussed, these reactions might be suitable for providing us with a detectable SUSY signal at LEP⊗LHC. The detailed discussion of the signatures as well

as that of the competing background has been postponed to a subsequent paper.

2 Cross Sections and Scenarios

The Feynman graphs for the basic subprocesses of the reactions

$$ep \to \tilde{\nu}\tilde{\chi}_i^0 X \ (i = 1, \ldots, 4),$$

$$ep \to \tilde{\nu}\tilde{\chi}_i^- X \ (i = 1, 2)$$

are shown in fig. 1. The relevant couplings can be deduced from the interaction Lagrangian of the minimal supersymmetric extension of the standard model (MSSM), see e.g. [4]. For the SUSY parameters we assumed as usual $M'/M = \frac{3}{5}\tan\theta_W$, $m_{\tilde{g}} = M \sin^2\theta_W \alpha_s/\alpha_{em} \simeq 3M$, with $\sin^2\theta_W = 0.228$ and $\alpha_s = 0.1$, and $\tan\beta = v_2/v_1 = 2$ (the numerical results are not very sensitive to the value of $\tan\beta$). For the masses of the gauge bosons we have used $m_Z = 91.2$ GeV, $m_W = 80.1$ GeV. Fig. 1

We shall present numerical results at $\sqrt{s} = 1.8$ TeV for two different mixing scenarios shown in table 1. For each of these mixing scenarios cross sections have been calculated for two different relations between sneutrino mass and squark mass: $m_{\tilde{q}} = m_{\tilde{\nu}}$ in scenarios (A.1) and (B.1)and $m_{\tilde{q}} = 4 \cdot m_{\tilde{\nu}}$ in scenarios (A.2) and (B.2). The last two scenarios (A') and (B') with $m_{\tilde{\nu}} = m_{\tilde{g}}$ and $m_{\tilde{q}} = \sqrt{2} \cdot m_{\tilde{\nu}}$ are motivated by renormalization group relations coupling the sfermion masses and the gaugino mass parameter M of the MSSM [6]. Allowing an error of at most 4% for the sneutrino and squark masses this choice is for values of M between 45 GeV and 450 GeV (and $\tan\beta = 2$) compatible with the mass relations given in [6]. The value of μ in scenarios (A') and (B') is the same as in scenarios (A) and (B), respectively. Notice, however, that in these scenarios both the mass and the mixing character of the neutralinos and charginos depend on the respective value of the sneutrino mass. Table 1

For the momentum transfer square $Q^2 = -(p_{q_{out}} - p_{q_{in}})^2$ to the quark we impose a cut with $Q^2_{cut} = 10(\text{GeV})^2$. While the dependence on Q^2_{cut} is approximately logarithmic for graphs (a), (b), (e) with photon exchange those with exchange of massive gauge bosons and charginos are not very sensitive on this cut. The final step in the evaluation of the cross sections consists in folding those for the parton subprocesses with the quark distribution functions $f_q(x, \tilde{Q}^2)$ of Glück, Reya and Vogt [7] for the valence quarks and the u, d, s sea quarks. The situation is somewhat more complicated than for slepton-squark production since in our case the momentum transfer to the nucleon depends on the respective reaction mechanism in fig. 1. We have, however, numerically

checked that in the kinematic region investigated here $\tilde{Q}^2 = \frac{1}{2}(sx - (m_{\tilde{\nu}} + m_{\tilde{\chi}})^2)$ is a satisfactory approximation. The errors involved are less than 10%.

For the squark width entering into the graph (c) all contributions from two-body decays have been taken into account. The integration was performed with the Monte-Carlo program *vegan*.

3 Numerical Results

3.1 The process $ep \to \tilde{\nu}\tilde{\chi}_i^0 X$

In figs. 2–5 we show the total production cross sections $\sigma(ep \to \tilde{\nu}\tilde{\chi}_i^0 X)$, $i = 1, \ldots, 4$, as a function of the sneutrino mass for the scenarios (A.1), (A.2), (B.1) and (B.2) at $\sqrt{s} = 1.8$ TeV. For comparison we give in the figs. also the corresponding cross section $\sigma(ep \to \tilde{\nu}\tilde{q}X)$ for associate sneutrino-squark production. We give no figs. for scenarios (A') and (B') since only for (A') the cross sections are only for the LSP $\tilde{\chi}_1^0$ and $m_{\tilde{\nu}} \leq 350$ GeV bigger than 10^{-2} pb (between 10^{-2} and 0.1 pb). The cross sections for scenario (B') are smaller than 10^{-2}pb.

As a consequence of the large W-couplings in the Feynman graphs (a), (b), (e) of fig. 1 the cross sections for zino like neutralinos are comparable to (scenario (B)) or even considerably higher (scenario (A)) than those for $\tilde{\nu}\tilde{q}$-production. Therefore the question which of the four neutralinos will be produced with the highest rate sensitively depends on the mixing scenario. Thus in scenario (A.2) the cross section for $\tilde{\chi}_2^0$ and in scenario (B.2) even that for the heaviest neutralino is the dominating one being ten times as large as that for the lightest neutralino $\tilde{\chi}_1^0$.

Since for pure photinos graph (b) does not contribute, the cross section for photino like neutralinos is much smaller than that for zino like neutralinos. For larger selectron masses also graph (a) is suppressed by the selectron prop-agator. The steep ascent of the cross sections for $\tilde{\chi}_1^0$ in scenario (A.1) and $\tilde{\chi}_3^0$ in scenario (B.1) originates from the contribution of graph (c), where for $m_{\tilde{q}} = m_{\tilde{\nu}}$ the squark approaches its mass shell in the accessible region of the phase space. Even the relatively small gaugino components of the light neutralinos $\tilde{\chi}_{1,2}^0$ in (B.1) suffice to produce this step in the cross sections. If, however, the zino component is strong enough, this effect will be suppressed by the strong contributions of the Feynman diagrams (a), (b), (e).

Since for pure higgsinos only graph (e) contributes, the cross sections for the heavy higgsino-like neutralinos $\tilde{\chi}_{3,4}^0$ in scenarios (A.1) and (A.2) are nearly

independent of the squark mass.

3.2   The process $ep \rightarrow \tilde{\nu}\tilde{\chi}_i^- X$

The total cross sections $\sigma(ep \rightarrow \tilde{\nu}\tilde{\chi}_i^- X)$, $i = 1, 2$ are shown in figs. 6–8. Due to the dominance of the contributions from gauge boson exchange in graphs (a), (b), (e), the numerical results are nearly identical for $m_{\tilde{q}} = m_{\tilde{\nu}}$ and $m_{\tilde{q}} = 4 \cdot m_{\tilde{\nu}}$. We therefore give the results for scenarios (A.1),(B.1) and (B') only. We give no results for scenario (A') since these results are quite similar to those in scenario (B'). Contrary to $\tilde{\nu}\tilde{q}$-production all partons are contributing to $\tilde{\nu}\tilde{\chi}_i^-$-production. Together with the strong Z-couplings in graphs (a), (b), (e) and photon couplings in graphs (b), (e) this leads for all scenarios to cross sections for $\tilde{\nu}\tilde{\chi}_i^-$-production being between one and two orders of magnitude larger than those for $\tilde{\nu}\tilde{q}$-production. The cross section is the highest for the light wino-like $\tilde{\chi}_1^-$ in scenario (A.1) but even for the heavy wino-like $\tilde{\chi}_2^-$ in (B.1) it is considerably larger than that for $\tilde{\nu}\tilde{q}$-production and also larger than that for the light higgsino-like state $\tilde{\chi}_1^-$, with substantial contributions from graph (e) only.

In contrast to sneutrino-neutralino production also for scenarios (A') and (B') the cross sections for $\tilde{\nu}\tilde{\chi}_i^-$-production are larger than 10^{-2} pb in a wide range of parameter space and considerably larger than those for $\tilde{\nu}\tilde{q}$-production. Notice that in scenarios (A') and (B') the mass values as well as the couplings of both chargino states are varying with increasing sneutrino mass: For the lower values of $m_{\tilde{\nu}}$ the light chargino is wino-like and the heavy chargino is more higgsino-like. The situation changes with increasing $m_{\tilde{\nu}}$ so that the light chargino becomes more and more higgsino-like whereas the heavy one becomes more and more wino-like. Simultaneously the mass of the heavy chargino is rapidly increasing, whereas that of the light chargino asymptotically approaches the value $|\mu|$. This interplay between mass and mixing character produces the two crossings of the cross sections in fig. 8 for scenario (B').

4   Signatures

In order to study the possible signals for associate sneutrino-neutralino/chargino production it is indispensable to include the decay of these particles as well as a discussion of the competing standard model background. Here we shall restrict ourselves to some remarks, postponing a more detailled discussion of signatures and background to a subsequent paper.

Light supersymmetric particles decay directly into the lightest neutralino

(which is assumed to be the lightest supersymmetric particle LSP and stable) and fermions, whereas heavy sparticles decay over complex cascades ending at the LSP. These cascade decays of heavy sparticles have two important consequences. On the one hand they will lead to events with besides one or several leptons, jets and missing energy one or two W or Z bosons in the final state [8]. On the other hand they can significantly enhance the possible signals of the respective process [9]. The actual decay patterns and the dominant signatures will, however, sensitively depend on the supersymmetric parameters and the slepton mass. Thus in scenarios (A.1) and (A.2) where the cross sections are the biggest for the processes $ep \to \tilde{\nu}\tilde{\chi}_2^0 X$ and $ep \to \tilde{\nu}\tilde{\chi}_1^- X$ the dominant signatures are $ej \not{E}$, $2ej \not{E}$ and $3ej \not{E}$ for $m_{\tilde{l}} = 100$ GeV and $ej \not{E}$, $2ej \not{E}$ for $m_{\tilde{l}} = 500$ GeV. For scenarios (B.1) and (B.4) on the other hand with $ep \to \tilde{\nu}\tilde{\chi}_4^0 X$ and $ep \to \tilde{\nu}\tilde{\chi}_2^- X$ as the dominant processes the favored signatures are $ej \not{E}$ and $Wj \not{E}$ for $m_{\tilde{l}} = 100$ GeV and $eWj \not{E}$ and $e2Wj \not{E}$ for $m_{\tilde{l}} = 500$ GeV (j denotes an arbitrary number of jets).

The most important sources of background are single W and Z production $ep \to \nu WX, \nu ZX$ and $ep \to eWX, eZX$ followed by the decays $W \to l\nu_l$, $Z \to \nu_l \bar{\nu}_l$ and $Z \to l^+ l^-$ giving rise to events with one, two or three charged leptons [3,10]. On the other hand the case of single top production $ep \to \nu \bar{t}bX$ followed by the decay $\bar{t} \to \bar{b}W^-$ gives rise to the $Wj \not{E}$ configuration and the neutral current process $ep \to et\bar{t}X$ is a source of the background for $e2Wj \not{E}$ events [11]. Since, however, the cross section for $t\bar{t}$-production is rather small ($\simeq 0.06$ pb for $\sqrt{s} = 1260$ GeV and $m_t = 180$ GeV), one would expect that this is the least dangerous of the competing standard model backgrounds. Detailed Monte Carlo studies taking into account the background are needed to assess the observability of the SUSY signal from associate sneutrino-neutralino/chargino production.

5   Conclusion

We have computed for representative gaugino-higgsino mixing scenarios the total cross sections for associate sneutrino-neutralino and sneutrino-chargino production at LEP⊗LHC. For wino-like charginos $\tilde{\chi}_i^-$, $i = 1, 2$ as well as for higgsino-gaugino mixtures they are between one and two orders of magnitude bigger than those for $\tilde{\nu}\tilde{q}$-production: about 0.1pb for $m_{\tilde{\nu}} = 500$GeV and between 1pb and 10pb for $m_{\tilde{\nu}} = 50$GeV. The cross sections for a light higgsino-like chargino are still one order of magnitude higher than those for $\tilde{\nu}\tilde{q}$-production.

The situation is less favorable for sneutrino-neutralino production. Here the cross sections are the highest for neutralinos with a strong zino component. For $m_{\tilde{q}} = m_{\tilde{\nu}}$ the cross sections for a zino-like neutralino are generally comparable

to those for $\tilde{\nu}\tilde{q}$-production. If, however, the squarks are appreciably heavier than the sneutrinos ($m_{\tilde{q}} = 4 \cdot m_{\tilde{\nu}}$) then in a mass region where the $\tilde{\nu}\tilde{q}$-cross section has already decreased to 10^{-4}pb that for a zino-like neutralino is still between 10^{-2}pb and 0.1pb.

Similar as for chargino production the question which of the neutralino cross sections is the dominating one depends much more on the mixing properties than on the mass of respective states. Thus in our scenario (B.2) even the cross section for the heaviest neutralino is for $m_{\tilde{\nu}} \geq 150$GeV the dominating one, being one order of magnitude beyond that for the lightest neutralino and surmounting that for $\tilde{\nu}\tilde{q}$-production.

Together with the subsequent decays of the produced sparticles this leads to interesting signatures consisting in up to four charged leptons, hadronic jets, missing energy and in case of scenario (B) massive gauge bosons. A quantitative analysis of these signatures will be postponed to a subsequent paper.

The size of the cross section obtained for sneutrino-chargino production, comparable to or even bigger than that for competing standard model processes, let us however suggest, that this process should provide an attractive channel in the search for supersymmetric events at LEP$\otimes$LHC.

Acknowledgements

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Table Captions

Table 1
 Neutralino and chargino states for scenarios (A.1), (A.2) and (B.1), (B.2) in terms of the weak eigenstates $(\tilde{\gamma}, \tilde{Z}, \tilde{H}_a^0, \tilde{H}_b^0)$ for neutralinos and $(-i\lambda^+, \psi_{H_2}^1)$ for charginos (see [5] for details of gaugino-higgsino mixing).

Figure Captions

Fig. 1: Feynman diagrams for the basic subprocesses $eq \to \tilde{\nu}\tilde{\chi}_i^0 q'$ $(eq \to \tilde{\nu}\tilde{\chi}_i^- q)$
Fig. 2: Cross sections in scenario (A.1) for the processes $ep \to \tilde{\nu}\tilde{\chi}_i^0 X$, with dashed line for $i=1$, dotted line for $i=2$, dash-dotted for $i=3$, dash-dot-dot for $i=4$ and solid line for $ep \to \tilde{\nu}\tilde{q}X$.
Fig. 3: The same as fig. 2 for scenario (A.2).
Fig. 4: The same as fig. 2 for scenario (B.1).
Fig. 5: The same as fig. 2 for scenario (B.2).
Fig. 6: Cross sections in scenario (A.1) for the processes $ep \to \tilde{\nu}\tilde{\chi}_i^- X$, with dashed line for $i=1$, dotted line for $i=2$ and solid line for $ep \to \tilde{\nu}\tilde{q}X$.
Fig. 7: The same as fig. 6 for scenario (B.1).
Fig. 8: The same as fig. 6 for scenario (B'), with the masses of the charginos $\tilde{\chi}_1^-$ and $\tilde{\chi}_2^-$ included.

		A	B
$\tan\beta$		2	2
μ		–219 GeV	–44 GeV
M		73 GeV	219 GeV
$\tilde{\chi}_1^0$		$m = 40$ GeV (–0.95,+0.30,+0.08,+0.08)	$m = 40$ GeV (–0.06,+0.13,–0.18,+0.97)
$\tilde{\chi}_2^0$		$m = 88$ GeV (–0.32,–0.89,–0.18,–0.27)	$m = 74$ GeV (+0.07,–0.33,+0.92,+0.22)
$\tilde{\chi}_3^0$		$m = 225$ GeV (+0.02,+0.20,+0.35,–0.92)	$m = 118$ GeV (+0.92,–0.32,–0.20,+0.06)
$\tilde{\chi}_4^0$		$m = 244$ GeV (+0.01,–0.27,+0.92,+0.29)	$m = 243$ GeV (+0.37,+0.88,+0.29,–0.04)
$\tilde{\chi}_1^+$		$m = 87$ GeV (+0.99,+0.10)	$m = 61$ GeV (+0.39,–0.92)
$\tilde{\chi}_2^+$		$m = 241$ GeV (–0.10,+0.99)	$m = 242$ GeV (+0.92,+0.39)

Table 1

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